ORIGINAL DOCUMENT BOOK

FINAL REPORT

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ZXE-9-18080-01

PROCESS DESIGN AND COST ESTIMATION FOR CELLULASE PRODUCTION EQUIPMENT

PREPARED FOR:

NATIONAL RENEWABLE ENERGY LABORATORY
Golden, Colorado
VOGELBUSCH PROJECT #9922

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VOGELBUSCH U.S.A., INC.
10810 OLD KATY ROAD, SUITE 107 • HOUSTON, TEXAS 77043

PROJECT DESCRIPTION & OBJECTIVES

The National Renewable Energy Laboratory (NREL) under the direction of the Office of Fuels Development at the U.S. Department of Energy has spent the past several years developing and testing processes for converting cellulose biomass to fuel ethanol. Although comprehensive reviews have been conducted of the overall process configuration, capital and operating costs, further knowledge is required in developing the cellulase enzyme production area.

The objectives of this work are, as follows

- To improve the process design and accuracy of the cost estimate for cellulase production. The current process has been modeled using the ASPEN+ system.
- To review and provide input specific to the oxygen transfer system of the cellulase production system.
- To specify and estimate potential designs of alternate cellulase production systems.
- To provide input on experimental work necessary to further develop this area of the cellulose conversion process.

This work has been carried out by:

Vogelbusch U.S.A., Inc.
10810 Old Katy Road, Suite 107
Houston, TX 77043

TASK 1 LITERATURE REVIEW

Literature provided by NREL as well as internal Vogelbusch research has been reviewed for design and oxygen requirements of cellulase production or similar systems. NREL currently uses equations developed under the BioEngineering Simulation Technology (BEST) program and an estimated oxygen transfer rate (OTR) requirement to determine aeration and agitation requirements for cellulase production.

A summary of the literature findings for both the external literature sources and internal Vogelbusch data review are tabulated on the following two pages. A reference list is provided at the end of this report and a copy of our Vogelbusch reference paper is included as Attachment A.

The external literature primarily presents oxygen transfer scenarios involving traditional, mechanically sparged systems. The oxygen transfer rates achieved exceeded the NREL experimentally established required oxygen uptake rate (OUR) of 25 mmol/L-h but the organisms used in the experimental work were not *T. reesei*. The organism itself is important because different organisms create different fermentation broth conditions. The oxygen supplying gas was air in all cases.

The internal Vogelbusch data review presents several different types of aeration systems. The oxygen transfer rates (OTR) exceed the required oxygen uptake rate in all cases but again, the organism tested was only *T. reesei* in one application. We do feel however, that the citric acid fermentation broth is similar in characteristics to a cellulase fermentation broth and therefore the Bubble Column oxygen transfer rate achievable will be similar to the test value.

A significant factor in the design and performance of the fermenter and oxygen transfer system is the pressure involved. If in-vitro sterilization under pressure is required and the vessel is designed for pressure then it is advantageous to run the vessel under pressure during normal operation in order to increase oxygen transfer. If a pressure vessel is not required, the fermenters can be much less expensive to construct but the efficiency of the oxygen transfer system itself becomes critical. The bubble column fermenters can be built for similar cost under either circumstance but the IZ fermenter cost will increase considerably with pressure required.

Another very important factor in reviewing oxygen transfer rates (OTR) is the viscosity of the fermentation medium. Further experimental work with an emphasis on measuring and monitoring the viscosity through the course of a cellulase batch is required in order to fully evaluate different oxygenation systems.

TASK 2 POTENTIAL DESIGNS OF CELLULASE PRODUCTION SYSTEMS

NREL currently has a design using standard low pressure reactors with top-driven agitation. Other potential designs could include, higher pressure reactors to increase oxygen solubility in the fermentation broth, use of oxygen enriched air, novel reactor designs and/or a combination of all of the above.

A potential alternate design that could be used to test both air and enriched air oxygen transfer is a bubble column fermentation system. This is the same system used by Vogelbusch for the production of citric acid. As mentioned previously, the broth characteristics of a citric acid fermentation are felt to be similar to that of a cellulase fermentation. The bubble column fermenter and subsequent aeration system regularly achieve oxygen transfer rates in excess of the required uptake rate of 25 mmol/L-h using air alone as the gas. This style of fermenter has a low capital cost and is easy to clean. It is also low shear which can be important in high oxygen required environments where traditional systems require a degree of mechanical agitation that is damaging to the organism.

Vogelbusch has developed a test system that could potentially be useful for experimental work. It is a laboratory scale citric acid production system. The system includes several glass, 17 L bubble column fermenters, a roots type compressor, air filters, flowmeters and associated instrumentation. Further details, an equipment list and process flow diagram are presented in Attachment B. If this test system is of interest to NREL, it could be purchased from Vogelbusch for a fixed price of $85,000. We would however stress that a laboratory scale system would not handle coarse suspended solids and a larger pilot plant fermenter would be required to test the system on converted cellulosic substrate. Vogelbusch can design such a test fermenter.

A modified NREL PFD as well as a Vogelbusch equipment list is also included illustrating the overall system for the current large scale production configuration. The material balance shown on the PFD is the original balance from NREL/TP-580-26157. The modifications to the current cellulase production area would include the replacement of the current fermenters with bubble column fermenters, the addition of recirculation pumps for the main cellulase fermenters and the associated recirculation piping. It is important to note that the maximum capacity of a bubble column fermenter is 590 m^3 (150,000 gallons). This results in a requirement for 20 fermenters in order to maintain the same overall system volume provided by the original 11 fermenters (280,000 gallons). The bubble column fermenters do not require coils or agitators however which results in a considerable equipment cost savings to offset the additional fermenter costs. A detailed breakdown is shown on the equipment list in Attachment B but in summary, an overall cost savings of approximately $3.6 million could potentially be realized.

An additional option to test would be a Mott Metalurgical gas sparger. These spargers are porous stainless steel and can be steam sterilized. They are also available designed specifically for sanitary service. The cost of these spargers is approximately $3,800 for sanitary service and process conditions described for Area 400 in the report NREL/TP-580-26157 and $3,125 for sanitary service and the process conditions described in the C Milestone Completion Report. In regards to both sets of quotations a ratio of approximately 1:1 H:D was used for vessel dimensions to be consistent with the ratio of H:D for the largest scale vessels, F-400. The price does not vary appreciably between the two units. These are standard items with a very broad range of air and liquid flows. We do not know the piping configuration of the current pilot plant but a recirculation loop with a dedicated pump for each fermenter is required for installation of these in-line spargers.

Prices have also been obtained for in-tank porous spargers that could be utilized in the cellulase seed vessels. These are very inexpensive units and again, the price is attractive even on the large scale. These in-tank spargers are approximately $125 - $135.

Mott Metalurgical was also contacted in regards to oxygen transfer rate data for the spargers but this information is very process specific. To this end, Mott is willing to discuss providing a "test" unit in both applications that could be used by NREL in the pilot plant to experimentally determine this data for the *T. reesi* fermentation. The equipment specifications for the two sets of spargers are included in Attachment B. These spargers could be utilized in both air only and oxygen enriched air applications.

A modified NREL PFD as well as a Vogelbusch equipment list is also included illustrating the overall system. The material balance shown on the PFD is the original balance from NREL/TP-580-26157. As mentioned previously, the modifications to the current cellulase production area would include the addition of recirculation pumps for the main cellulase fermenters and the associated recirculation piping. The equipment cost for the modifications is approximately $134,000. This is a very minor capital cost addition relative the estimated overall 400 area equipment cost of approximately $11,500,000.

TASK 3 FUTURE EXPERIMENTAL WORK

NREL has the capability of bench and pilot scale runs. In order to collect the data essential to the design of full-scale process equipment we suggest the following experiments be conducted:

- Cellulase production runs using existing pilot plant equipment with the emphasis on measuring the viscosity throughout the course of the batch. This is important for both oxygen transfer as well as heat transfer calculations.
- Cellulase pilot production runs using a bubble column fermenter(s) in order to measure the oxygen uptake rate and oxygen transfer rates in the fermentation broth utilizing this type of reactor (with and without pressure).

VOGELBUSCH U.S.A., INC.
10810 OLD KATY RD., SUITE 107
HOUSTON, TEXAS 77043
(713) 461-7374 / FAX: (713) 461-7377

- Cellulase pilot production runs using the Mott Metalurgical gas spargers to evaluate the oxygen transfer capabilities of this type of aeration system (with and without pressure).

- Cellulase production runs on an increasingly large scale in order to determine if sanitization requirements become a capital and/or operating cost issue.

- Cellulase production runs on an increasingly large scale in order to determine if the oxygen transfer characteristics and requirements become a capital and/or operating cost issue.

CONCLUSIONS AND RECOMMENDATIONS

The work to date involving the *T. reesi* organism indicates that the oxygen transfer rate required to meet the needs to the organism is not as high as originally anticipated. This transfer rate of 25 mmol/L h is achievable by a number of different aeration/oxygenation systems. A key factor to consider however is the fact that biological systems do not necessarily scale-up in a "linear" or predictable fashion. To this end we have suggested two alternate process designs for oxygen transfer systems over and above the traditional mechanical, sparged fermenter configurations. These alternate systems need to be tested but we feel will provide the anticipated oxygen transfer rate (with additional oxygen transfer capabilities if required) while minimizing the need to expose the organism to increasing levels of shear stress. These proposed systems also take into consideration the need to maintain close to aseptic conditions for optimal *T. reesi* growth and cellulase enzyme production. The bubble column fermenters are used in the citric acid process which also has a more stringent sanitation requirement than a traditional yeast fermentation and the Mott spargers are capable of withstanding steam sterilization and/or exposure to cleaning chemicals (i.e., caustic, various acids).

Most reported work involving the evaluation of oxygen transfer capabilities has been conducted on organisms other than T. reesi. As mentioned previously, oxygen transfer rates are very process specific. Further testing, as described under Task 3, is necessary in order to define the operating conditions necessary for the production of cellulase enzymes by T. reesi. These operating conditions are required in order to identify opportunities for further improving the economics of the cellulase production process.

Attachment A - Reference List of NREL supplied literature

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EXPERIENCE in BIOREACTOR OPERATION

at VOGELBUSCH

1. INTRODUCTION

Unfortunately the title of the lecture is so widespread that a comprehensive treatment is beyond the scope of this symposium mainly due to the reason that VOGELBUSCH has designed and operated more than approximately 100 bioreactors for aerobic processes on industrial scale ranging from 10 up to 600 m^3 gross volume (1000 m^3 under construction).

These fermenters are in operation throughout the world on different raw materials and products and therefore a quantitative comparison based on theoretical models can be applied only to a few parameters because measurement of various model parameters (as e.g. bubble diameter distribution) in practice is not only tedious but in some cases effectively impossible.

What we will try anyway is to give some critical illustration upon the term "performance" in connection with bioreactor design and operation as well as some qualitative criteria for selection of a special type of bioreactor.

2. TYPES OF BIOREACTORS

Aerobic bioreactors are usually distinguished by their aeration system and generally this seems to be the parameter of utmost importance. The types under consideration within this lecture are as follows:

- bubble column or air lift type aeration
- VOGELBUSCH self-priming aeration (VB-IP 8)
- VOGEL8USCH high efficiency aeration (VB-EB 4)
- IZ-deep jet aeration system

2.1 Bubble Column Fermenters

This type of fermenter has become very popular within the past years mainly due to the facts that the construction of the aeration device is rather simple and that there seems to be sufficient literature data available for design and scale-up.

The aeration device usually consists of a pipe distribution system with a large number of small bores, distributing the air evenly near the bottom of the fermenter. Besides mechanical characteristics of the construction of the sparger system and the properties of the fermentation liquid the oxygen transfer relates mainly to the quantity of air introduced and the height of the liquid column. Similarly the oxygen utilization increases with the liquid height nearly linearily.

As a consequence, fermenters of this type generally are of slim construction with a height/diameter-ratio of at least 3, but up to 20 and more.

Some qualitative characteristics of this type of fermenter are shown in Table 1.

TABLE 1

CHARACTERISTICS of BUBBLE COLUMN FERMENTERS

AERATOR TYPE	STATIC
CONSTURCTION	SIMPLE
INVESTMENT	LOW
OTR*) Limits	LOW - MEDIUM specific gas load Liquid height
OXYGEN UTILIZATION	LOW – MODERATE
ENERGY DISSIPATION	BOTTOM AREA
DEFOAMING	MODERATE
CLEANING	EASY

*) OTR relatesto u_g n, u_g = superficial gas velocity

resp. to $(P*H_l/ \ln (l+.1*H_l))^{\wedge n}$

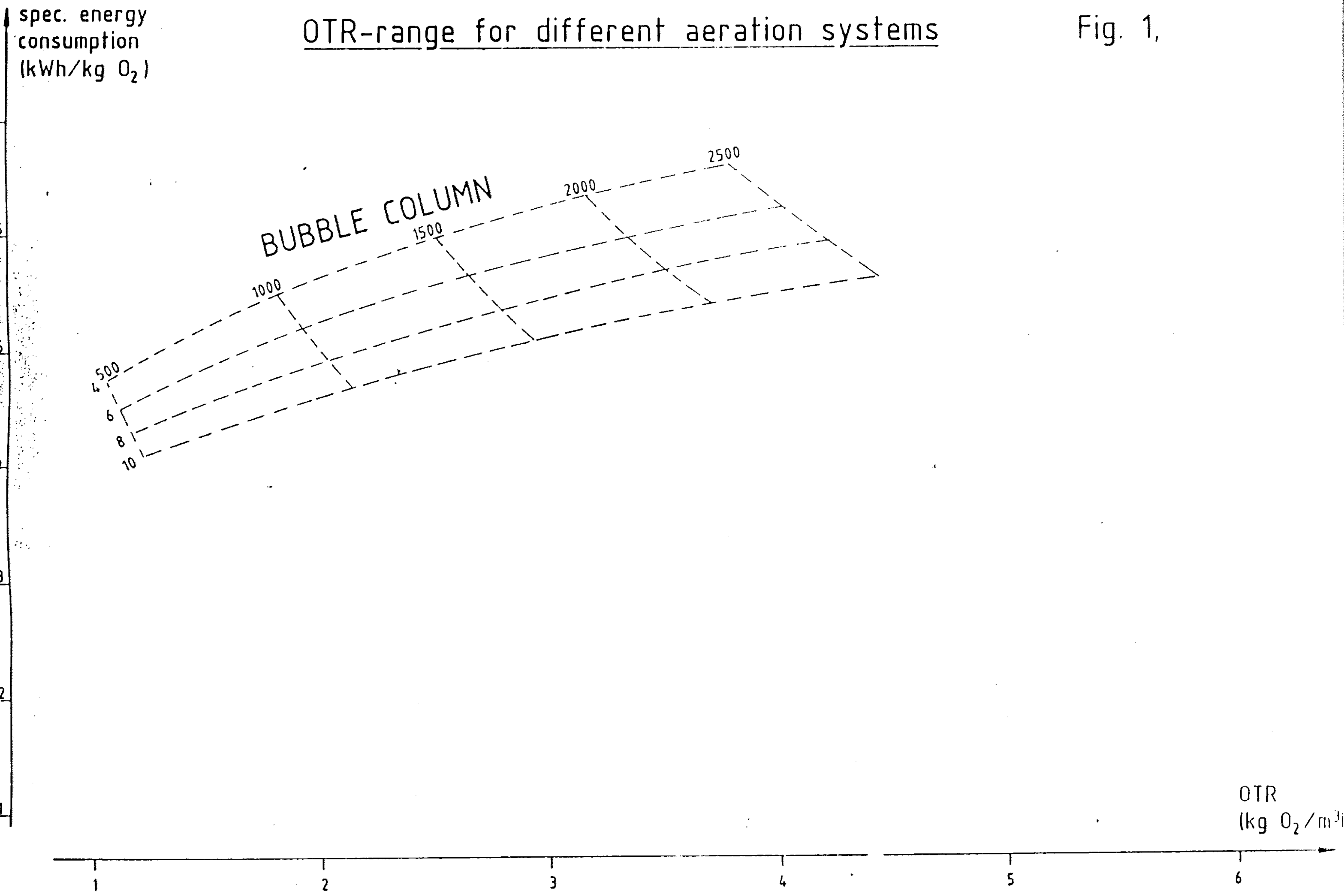
All these above mentioned properties relate to standard constructions with no excessive height/diameter - ratio (H/D < 6) and to coarse bubble systems.

If we look closer upon the oxygen transfer properties it is generally accepted for coarse bubble systems (bubble diam. > lmm) that liquid side mass transfer $K_{l}a$ is proportional to superficial gas velocity u_g powered by an empirical constant, n; the magnitude of this constant should range from about 0.7 - 0.8; the superficial gas velocity is defined as the linear gas velocity in the void column volume and therefore equivalent to the specific gas load per unit area; due to the interrelationship between $k_{l}a$ and OTR (OTR = kla(c* - c)) for aqueous systems there results a similar relation between OTR and u_g Additionally, the power input per unit volume can easily be linked with the superficial gas velocity via specific gas load (gas flow per unit area) and isothermic work of compression; the resulting relation reflects the interdependency of specific power input, column height and OTR. A graphical presentation of these dependencies is shown on the following figure.

Fig. 1

OTR-range for different aeration systems

Fig. 1,



The ordinate scale shows the OTR [kg $0_2/m^3.h$], whereas the abscissa reflects the specific energy demand [kWh/kg 02] per transfer unit. The area covered ranges from about 1to 4 kg 02 per hour with specific energy demand from approx. 0.4 to 0.65 kWh per kg Oxygen. The additional parameters reflect specific power input per unit volume (500 – 2500 W/m^3) and the ungassed liquid height of the bubble column (4 - 10 m)

Increasing the oxygen transfer may either be achieved by increasing the specific power input or the liquid height. Reduction in specific energy demand may be achieved by increasing the column height, but it has to be considered that the inclination of the lines of constant power input decreases with increasing values.

Of course the construction of bubble columns with liquid heights of more than 10 m is possible and would be necessary for efficient energy utilization as well as for achieving higher OTR - values but in practice very high columns are no longer of simple construction (nutrient distribution) and low investment (civil works, screw compressor instead of roots-type blower) as indicated in Fig. 1 and therefore loses some of the specific advantages of the bubble column.

Increasing the specific power input has also certain limits as it is connected with increasing specific gas load (= superficial gas velocity); first, the gas hold-up increases with increasing u_g resulting in low net volumes and second, distributing the gas can be of some problem as specific gas load exceeds approx. 1000 $m^3/m^2.h$ (u_g = .28 rn/sec) for OTR of 4 kg/m^3 .h

To obtain this general view several simplifications had to be made and perhaps some specific features of bubble column operation have not been presented in detail, but according to our experience the following conclusions can be drawn:

The advantages of bubble columns regard mainly to their simple construction, low investment and easy cleaning; with these characteristics OTR's of approx. 2 - 3.5 kg/m^3 .h can be achieved. The specific energy consumption is in the range of .5 - .65 kWh/kg Oxygen. Expanding the application range towards higher transfer rates results in the loss of the specific advantages due to sophisticated construction and even higher specific energy consumption.

2.2 VB - IP 8 Self – Priming Aeration

This type of aeration is essentially dynamic and consists of a stator with leading function and an impeller - type rotor. The construction is rather simple, although details may considerably effect efficiency. This is demonstrated drastically by improvements regarding OTR and energy consumption up to 30 % merely by optimizing mechanical construction within the past years.

Some general characteristics of this fermenter type are shown on the following table:

TABLE 2

CHARACTERISTICS OF SELF-PRIMING AERATION

AERATOR TYPE	DYNAMIC
CONSTRUCTION	SIMPLE
INVESTMENT	LOW
OTR *) Limits	LOW – MEDIUM Liquid height
OXYGEN UTILIZATION	HIGH
ENERGY DISSIPATION	BOTTOM AREA
DEFOAMING	POOR – MODERATE
CLEANING	MODERATE

The oxygen transfer of this aeration system is directly related to the impeller speed as this is the only energy input to the system. Energy dissipation takes place only in a part of the bottom area resulting in high energy inputs locally causing the generation of fine bubbles and large contact area; on the other hand these bubbles have only little rising velocities and therefore long residence time in the system. As a consequence this aeration system achieves extremely high oxygen utilization (35 - 45 %) but only low to moderate OTR's (typically 1 – 3 kg $0_2/m^3$ .h). The optimum application range is indicated in fig. 2 with OTR from about 1 – 2 kg/m^3.h and a corresponding specific energy input of approx. 0.25 - 0.35 hWh per transfer unit. Increasing the OTR to approx. 3 kg/m^3 is possible by increasing the aerator power resulting in specific energy demand of abt. 0.55 kWh per transfer unit.

A physical limit to the application of this aeration system is the suction height and therefore the liquid height of the mash is limited to approx. 5m. As a consequence fermenter volume is usually smaller than 150 m^3.

2.3 VS - EB 4 High efficiency aeration

The high efficiency aeration is a dynamic system, which combines mechanical agitation and external blower as construction elements. Air enters the agitator blades through a hollow shaft and is distributed to the liquid throughout the open rear side of the agitator blades.

General characteristics are as follows:

TABLE 3

CHARACTERISTICS OF HIGH EFFICIENCY AERATION

AERATOR TYPE	DYNAMIC
CONSTRUCTION	DIFFICULT
INVESTMENT	MODERATE
OTR Limit	MEDIUM specific gas load
OXYGEN UTILISATION	MODERATE
ENERGY DISSIPATION	BOTTOM AREA
DEFOAMING	GOOD
CLEANING	EASY

The High - Efficiency Aeration is probably one of the most extensively used systems because it allows for OTR's of 3.6 - 4.1 kg/m^3.h which cannot easily be obtained with other systems together with extremely low energy consumption of approx. 0.45 - 0.50 kWh/kg 0_2. Oxygen utilization is approximately 20%; by the special design of the aerator these results can be achieved with only moderate liquid heights of usually less than 6m (even with 220 m^3 Fermenter volume) where still Roots-type blowers can be applied.

The limits of this aeration system are the gas distribution capacity of the agitator for achieving higher transfer rates; another application limit is the comparatively high investment costs for small scale equipment (fermenter volume smaller than 50 m^3).

2.4 IZ - deep jet aeration system

The IZ - deep jet aeration is a self - priming, dynamic system, where aeration is effected by means of an external recirculation pump(s) which draw(s) off mash from the bottom of the fermenter and transfer(s) it via an external loop - usually combined with heat exchanger - to the top of the recirculation duct from where it falls back to the fermenter by gravitation simultaneously aspiring air (similar to a water jet pump) and immersing it into the liquid.

General characteristics of this aeration type are listed below:

TABLE 4

CHARACTERISTICS of IZ - DEEP JET AERATION

AERATOR TYPE	DYNAMIC
CONSTRUCTION	DIFFICULT
INVESTMENT	MODERATE
OTR	MEDIUM - HIGH
Limits	(Pump efficiency)
OXYGEN UTILIZATION	MODERATE
ENERGY DISSIPATION	TOTAL LIQUID
DEFOAMING	EXCELLENT
CLEANING	DIFFICULT

In contrast to the previously mentioned systems, energy dissipation takes place throughout the whole liquid nearly homogeneously which seems to be the main reason for the high achievable OTR's. Additionally, the aerator device is 'modular' so depending on the required oxygen transfer the necessary number of aerator pumps can be applied. As a result with this system OTR's of up to 12 kg/m^3 .h can be achieved; the only limit for the OTR of this system seems to be the efficiency of the aerator pump.

Although being a specially designed pump for efficient transfer of highly gas containing liquids there is still a certain decrease in efficiency with aqueous fermentation liquids of densities ranging from 600 to 400 kg/rn^3. Therefore the specific energy consumption per transfer unit shows a slight increase with increasing OTR. Generally this system is capable of OTR's from below 4 up to 12 kg/m^3.h, with the optimum range around 5 - 8 requiring approx. 0.55-0.7 kwh/kg 0_2 (Fig. 2).

Another special feature of this aeration system is in regards to the excellent defoaming properties caused by mechanical foam destruction of the immersing liquid jet.

Despite these advantages there are some application limits. Regarding oxygen transfer the system is not suitable for very low OTR's due to limited radial aeration action below approx. 2 kg/m^3.h;

In addition cleaning of the system is difficult on large scale making monoseptic processes problematic, although on pilot scale sterile operation makes no problem (cellulase production with Trichoderma in 300 1 fermentors).

2.5 Summary

The aim of this part of the lecture was to show that any of the above mentioned aeration systems has a certain application range and special properties which are not subject to mathematical modeling but can only be explored empirically, as e.g. defoaming, cleaning properties or shear stress.

On the other hand we can see the development of fermenters just - as it seems - from an academic point of view leading to bubble columns of 24 m height with 0.6 m diam. loosing all the advantages of the previously simple construction.

Any of these aeration systems has its special field of application resulting from its OTR - capability in connection with various other properties.

3. PRODUCT OR PROCESS REOUIREMENTS

Perhaps a serious misunderstanding refers to the purpose of an aerobic fermenter or aeration system. The purpose is not only to supply oxygen in sufficient quantity for the biological process but to serve for all the environmental conditions necessary for the process (including raw material, organism and product(s)). Fermenter performance has however additional aspects, summarized by economy; from the different configurations possible the one with the best economic properties will be chosen, whereas economic properties vary considerably with product type, production scale and infrastructure.

Some requirements for different products of aerobic fermentations are listed below:

TABLE 5

PROCESS or PRODUCT REQUIREMENTS

	VINEGAR	CITRIC ACID	BAKER'S YEAST	FODDER YEAST
OTR	LOW	LOW	MEDIUM	MEDIUM-HIGH
CONTAMINATION RISK	LOW	HIGH	MODERATE	LOW
PRODUCTION SCALE	SMALL	LARGE	VARIOUS	VARIOUS
TYPICAL RAW MATERIAL	ETHANOL	MOLASSES GLUCOSE	MOLASSES	MOLASSES SULFITE LIQUOR
CULTIVATION TYPE	FED BATCH	FED BATCH	FED BATCH	CONTINUOUS
CYCLETIME	24 h	120 h	24 h	-

Regarding the process requirements listed above, vinegar production is usually performed on small scale in a fed-batch process. The OTR requirement is low as well as the contamination risk.

Theoretically a bubble column fermenter would fulfill all these requirements, but the specific energy demand would be considerably higher than with the self-priming VB-IP 8 system; besides a bubble column in this case would exhibit another serious disadvantage: because of the low oxygen utilization (12 to 15 % on such a small scale) the three- or four-fold amount of air would be necessary as compared to the self-priming system resulting in proportionally higher losses of the volatile raw material which is present in considerable amounts throughout the whole batch.

Concerning Citric Acid production we face a fed-batch process with comparatively long cycle times of approx. 120 hours; During the first 48 to 60 hours, until considerable acidification has taken place, there is a high risk of biological contamination. In combination with the usually large production scale (fermenter volumes > 200 m^3) and the low OTR requirements this is a typical application for bubble column fermenters.

If we consider now the process requirements for baker's yeast production there is no convincing reason for the particular application of one of the above mentioned aeration systems. In fact VOGELBUSCH has built plants for baker's yeast production and Active Dry Yeast production with all the mentioned systems which operate satisfactorily with excellent product quality.

As a matter of fact the OTR should however not be much lower than 3 $kg/m^3.h$ and should on the other hand not exceed 7 $kg/m^3.h$; these limits are somewhat diffuse and result mainly from efficient process performance and physiological requirements of the product. This example shows that there are no objective criteria based on theoretical considerations which allow for the selection of one particular aeration system not even for a certain product.

From our experience we recommend for medium- and large- scale production the well-proven High-Efficiency-Aeration because of it's good OTR (despite reasonable fermenter height), good defoaming properties and uniquely low energy consumption. For small-scale production we usually apply bubble columns with respect to their simple construction.

For the future however the improved self-priming aeration IP-8 presents an interesting alternative to the bubble column system for small-scale production of baker's yeast as it is even simpler in construction and operation and requires less energy per transfer unit.

The reasons for this application ranges are however not performance criteria like OTR, oxygen utilization, liquid mixing properties or whatever, but simple considerations regarding investment resp. operating costs.

Continuing with fodder yeast production we face usually medium- high OTR requirements which require either the application of the High-Efficiency-Aeration or the IZ-deep-jet system. Both have been applied successfully with molasses substrate, but if we change to Spent Sulfite Liquor (SSL) as another possible substrate we face a completely different situation. Today's sulfite mills usually operate on a scale of more than 100 000 tons per year, generating streams of SSL between 100 and 300 m3 per hour; with a residence time of 3 to 4 hours liquid volumes of 1000 m3 and more have to be handled in a continuous process.

In such a case the 'modular' design of the IZ-deep-jet aeration system is of special advantage because it allows for the design of the required oxygen transfer (just by simply selecting the number of pumps) independent of the fermenter size. On the other hand the fermenter size can be increased easily up to volumes of 1000 m^3 and more just according to process requirements; last -but not least - the excellent defoaming properties are a convincing argument for this aeration system for anyone who has to handle this product from that raw material.

4. SUMMARY

An important feature for the characterization of aerobic bioreactors regarding their aeration systems may be the Oxygen Transfer Rate achievable with the respective system. The four systems discussed have different ranges of application in terms of OTR, ranging from

- 1-3 kg $0_2/m^3$.h for the self-priming IP-8 system
- 2-3,5 kg $0_2/m^3$.h for the bubble column
- 3,6-4,1 kg $0_2/m^3$.h for the high efficiency aeration
- 4-12 kg $0_2/m^3$.h for the IZ - deep -jet aeration

To achieve these transfer rates various amounts of energy are required ranging from 0.25 up to 0.65 kWh per transfer unit, generally increasing for any system with increasing transfer rates. The selection of a particular aeration system for a certain process merely from the OTR capactity is not possible due to

- Applicability of different systems for one OTR (fig. 2)
- OTR-requirements from process are usually not stringent, meaning that a process usually can be operated within a certain region of OTR

The second selection criterion might be the efficiency of the aeration, i.e. the energy demand per transfer unit; as explained above the aeration systems differ widely in the efficiency, especially the bubble column shows considerable dependence on simple design parameters such as column height or gas flow rate. The efficiency however is an economic criterion and has to be considered with the overall economy of the plant, including investment for civil works, equipment, e.t.c., as well as operating costs. Therefore the efficiency of the aeration has always to be harmonized with the scale of production.

As a conclusion we have to confess that the requirements for a bioreactor are always specified by the process, and only within these limits the term 'performance' can be defined from a practical point of view. This complex 'performance' has various aspects, as has been pointed out within this lecture, as e.g. OTR, which are only to a small extent subject to theoretical treatment.

The resulting situation is that there are processes who 'tolerate' based on their requirements only one special aeration system, e.g. Citric Acid fermentation; but also in this case the decisive criterion is not OTR. Other processes tolerate a wide range of aeration systems (e.g. baker's yeast production) and then the answer to the question of the best-suited system (= performance) depends on a large number of variables, like production scale, energy costs, climatic conditions and cannot be answered generally.

VOGELBUSCH GmbH
Blechturmgasse 11
A-1050 Vienna
Austria

Bubble column test fermenters

BRIEF DESCRIPTION OF THE BUBBLE COLUMN TEST FERMENTER STATION

The following description refers to the P & I diagram 94503-CA-07-0701, (as an example from a pilot plant for citric acid production). The raw material preparation has to be adopted according to the needs of different processes and is therefore not part of this description. Also, the description of the fermenter operation is basically as required for a citric acid fermentation and should serve as an indication of the specific operation of such fermenters ***and would have to be adapted to the needs of different processes.***

System description:

Air supply: Air is delivered by a roots-type compressor (oil-free air outlet). Air amount depends on the needs of the process and the compressor has to be dimensioned **accordingly.**

The air passes a pre-filter and a steam resistant sterile filter in the main supply pipe. The piping system allows sterilization of the air supply piping system by steam.

The air distribution system on the rear side of the racks allows steaming of each fermenter, while all others are still in operation.
The air amount is adjusted by a flow meter (Rota-type) for each fermenter.

Steam supply: Steam is delivered either from an electrical heated boiler or from existing steam system. In this case, pre-filtration of steam will be necessary to avoid problems caused by particles.

Process water: Process water is used for filling of the thermostated water baths and for general purposes such as cleaning, etc.

Hot water: Hot water is used for general purposes such as cleaning, etc.

Demineralized water: Demineralized water is used for compensation of evaporation losses.
It is sterilized by standard sterile filter cartridges (e.g. from Millipore).

VOGELBUSCH GmbH
Blechturmgasse 11
A-1050 Vienna
Austria

Bubble column test fermenters

Test fermenters: The test fermenters are made of glass with 17 liters gross volume (6 pieces per rack). Other materials in contact with the medium are of poly-propylene and rubber only.

Air (and steam) is distributed by a sparger with several fine bores near the bottom of the fermenter. Air flow is controlled by a flow meter (Rota-type).

Mixing: In a bubble column mixing is done by air only and the performance is strictly correlated to the aeration rate. Therefore a certain minimum air flow is required for sufficient mixing.

Temperature adjustment: The test fermenters are hooked up in the rack and a part of the fermenters are immersed in a thermostated water bath. Temperature of the fermented mash would increase as a result of heat evolved by the process. This heat is compensated by the evaporation rate and temperature of the water bath. A TI is located in the rubber-stopper of the sampling nozzle for monitoring the temperature of the fermented mash.

Option: Direct control by TI from one fermenter to the thermostat.

Foam control: By height-adjustable conductivity sensors and relays with adjustable on/off time, which operate on a peristaltic pump. The antifoam agent is introduced into the fermenter through a silicone septum, which is located in the fermenter cover.

Compensation of evaporation losses: The test fermenters are connected to a balance with a contactor. The contactor operates on an on/off relay that controls a peristaltic pump to add makeup water. The make up water is stored in a storage bottle which is located on a shelf on the rear side of the rack. The make up water is introduced into the fermenter through a silicone septum, which is located in the fermenter cover.

pH-monitoring: A pH-probe is located in the rubber-stopper of the sampling nozzle.

Option: Automatic pH-control of fermented mash by addition of acid or alkali respectively.

Sampling: Sampling is done through a glass pipe dipping into the fermentation broth and is located in the stopper of the sampling nozzle. The slight over pressure in the fermenter is sufficient to press out liquid.

Operation description:

Usually the medium is prepared in concentrated form, filled into glass bottles and sterilized in an autoclave.

VOGELBUSCH GmbH
Blechturmgasse 11
A-1050 Vienna
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Sterilization of the test fermenters: The test fermenters are sterilized by live steam without back pressure. The fermenters are placed upside down in the rack, so that the steam condensate flows out via the hose of the exhaust air. After sterilization the air is switched on, to allow the residual steam to dissipate and to cool down the fermenters and to maintain a slight over-pressure.

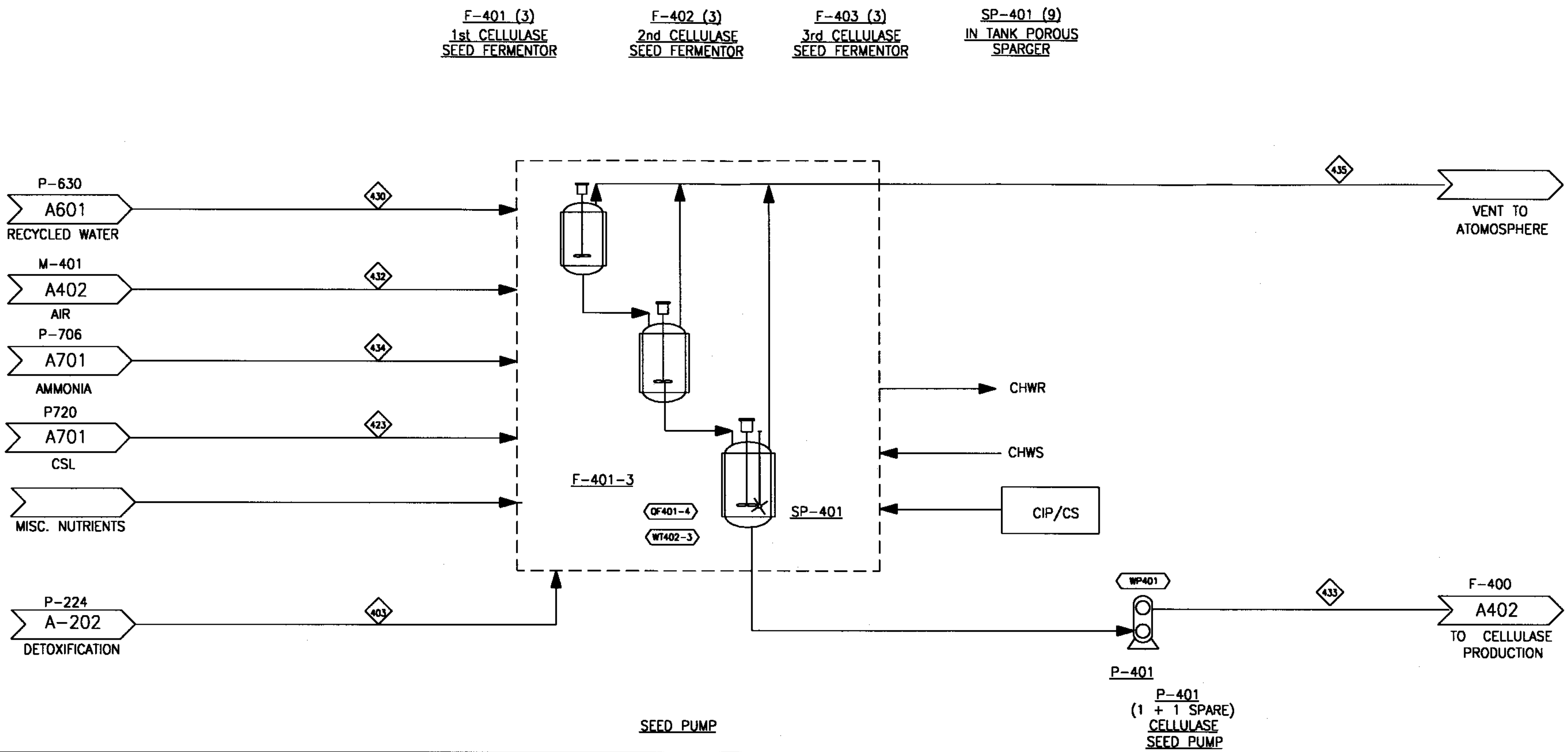
Filling of fermenters: After sterilization the fermenters are turned around in upright position and sterile filtered demineralized water, concentrated media and nutrient salts are added. The nutrient salts might be dissolved in small bottles and before addition to the fermenter the bottles are sterilized in a small sterilizer. Addition of small liquid amounts might be done by a syringe equipped with a sterile filter through a silicone septum located in the fermenter cover.

pH-adjustment: If necessary the pH is adjusted by addition of acid or alkali respectively. pH can be followed up by the pH probe during addition. An increased aeration rate shortens mixing time.

When all additions and adjustments have been done a start sample can be taken and start weight and filling volume are recorded. The antifoam and water addition system (to compensate the evaporation losses) is hooked up. The antifoam and water addition system (to compensate the evaporation losses) are hooked up. The air is adjusted to the desired value and the fermenters are ready for inoculation. The temperature of the fermenters is adjusted via water bath equipped with thermostat.

Normal operation: The main procedures for normal operation are usually **sampling,** analyses, re-filling of water bath and storage bottles for make up water and antifoam agent, addition of substances, data recording and observation of unusual events.

End of fermentation: At end of the fermentation the air is stopped, the level measured and after mixing again with air, the final sample is taken and analyzed. The fermentation broth is discharged and the fermenters are disassembled, cleaned and ready for the next start.



STREAM NUMBER	UNITS	403	423	430	432	433	434	435
STREAM NAME								
TOTAL FLOW	kg/hr	957.0	30.0	2,147.0	20,928.0	2,580.0	8.0	21,488.0
INSOLUBLE SOLIDS	%	16.2%	0.0%	0.2%	0.0%	4.7%	0.0%	0.0%
SOLUBLE SOLIDS	%	6.3%	100%	1.1%	0.0%	1.7%	0.0%	0.0%
TEMPERATURE	°C	59	28	47	40	28	28	28
PRESSURE	atm	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ETHANOL	kg/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WATER	kg/hr	731.0	0.0	2,084.0	0.0	2,382.0	0.0	501.0
GLUCOSE (SS)	kg/hr	7.0	0.0	0.0	0.0	0.0	0.0	0.0
XYLOSE (SS)	kg/hr	36.0	0.0	2.0	0.0	0.0	0.0	0.0
ACETIC ACID	kg/hr	4.0	0.0	7.0	0.0	10.0	0.0	1.0
CELLULOSE (IS)	kg/hr	86.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHERS	kg/hr	93.0	30.0	54.0	20,928.0	188	8.0	20,986.0

DWG. No.	REFERENCE DRAWINGS	No.	DATE	REVISION	BY	CK'D	APPR.
		A	01/25/00	PRELIMINARY	RML	PT	

ENGINEERING RECORD
DATE: 01/25/00
SCALE: NONE
DRAWN BY: LANIER
CHECKED BY: PT
APPROVAL:
APPROVAL:

VOGELBUSCH USA, INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS

NREL NATIONAL RENEWABLE ENERGY LABORATORY
Biotechnology Center For Fuels And Chemicals

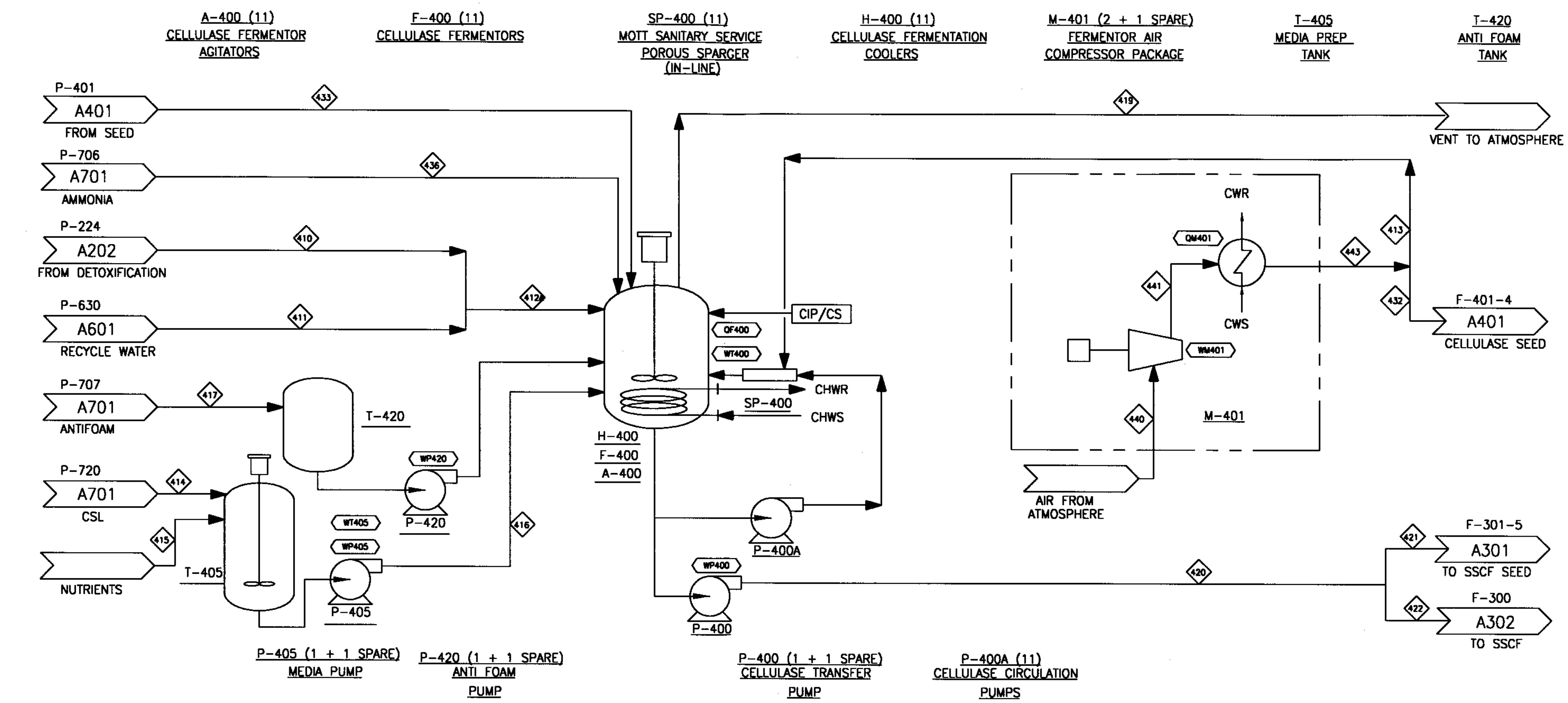
NREL

PROCESS FLOW DIAGRAM
SECTION A400
CELLULASE SEED FEMENTATION

PROJECT NUMBER	DRAWING NUMBER	
9827	D-400-N-A401	A
Client	Size / Area / Type / Sequence	Rev.

D400NA401.DWG

02/10/00



STREAM NUMBER	UNITS	410	411	412A	413	414	415	416	417	419	420	421	422	432	433	436	440	441	443	-	-	-	-	-	-	-	-	-	-	-	-	-
STREAM NAME																																
TOTAL FLOW	kg/hr	18,176.0	22,784.0	40,960.0	301,966.0	406.0	174.0	580.0	227.0	307,253.0	39,217.0	3,922.0	35,296.0	20,928.0	2,580.0	157.0	322,894.0	322,894.0	322,894.0													
INSOLUBLE SOLIDS	%	16.2%	0.2%	7.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.6%	5.6%	5.6%	0.0%	4.7%	0.0%	0.0%	0.0%	0.0%													
SOLUBLE SOLIDS	%	6.3%	1.1%	3.4%	0.0%	100.0%	0.0%	69.9%	0.0%	0.0%	1.7%	1.7%	1.7%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%													
TEMPERATURE	°C	59	47	48	40	28	28	28	28	28	28	28	28	40	28	28	20	169	40													
PRESSURE	atm	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.66	1.66	1.66	1.66	1.00	1.00	1.00	1.00	3.00	1.00													
ETHANOL	kg/hr	3.0	3.0	6.0	0.0	0.0	0.0	0.0	0.0	4.0	2	0.0	2.00	0.0	0.0	0.0	0.0	0.0	0.0													
WATER	kg/hr	13,880.0	22,117.0	35,996.0	0.0	0.0	0.0	0.0	0.0	4,263.0	35,489.0	3,549.0	31,940.0	0.0	2,382.0	0.0	0.0	0.0	0.0													
GLUCOSE (SS)	kg/hr	128.0	0.0	128.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
XYLOSE (SS)	kg/hr	682.0	19.0	701.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
ACETIC ACID	kg/hr	79.0	78.0	157.0	0.0	0.0	0.0	0.0	0.0	12.0	155.0	15.0	139.0	0.0	10.0	0.0	0.0	0.0	0.0													
CELLULOSE (IS)	kg/hr	1,634.0	3.0	1,636.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0													
OTHERS	kg/hr	1,770.0	564.0	2,336.0	301,966.0	406.0	174.0	580.0	227.0	302,974.0	3,571.0	358.0	3,215.0	20,928.0	198.0	157.0	322,894.0	322,894.0	322,894.0													

DWG. No.	REFERENCE DRAWINGS	No.	DATE	REVISION	BY	CK'D	APPR.
		A	01/25/00	PRELIMINARY	RML	PT	

ENGINEERING RECORD
DATE: 01/25/00
SCALE: NONE
DRAWN BY: LANIER
CHECKED BY: PT
APPROVAL:
APPROVAL:

VB
VOGELBUSCH USA, INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS

NREL NATIONAL RENEWABLE ENERGY LABORATORY
Biotechnology Center For Fuels And Chemicals

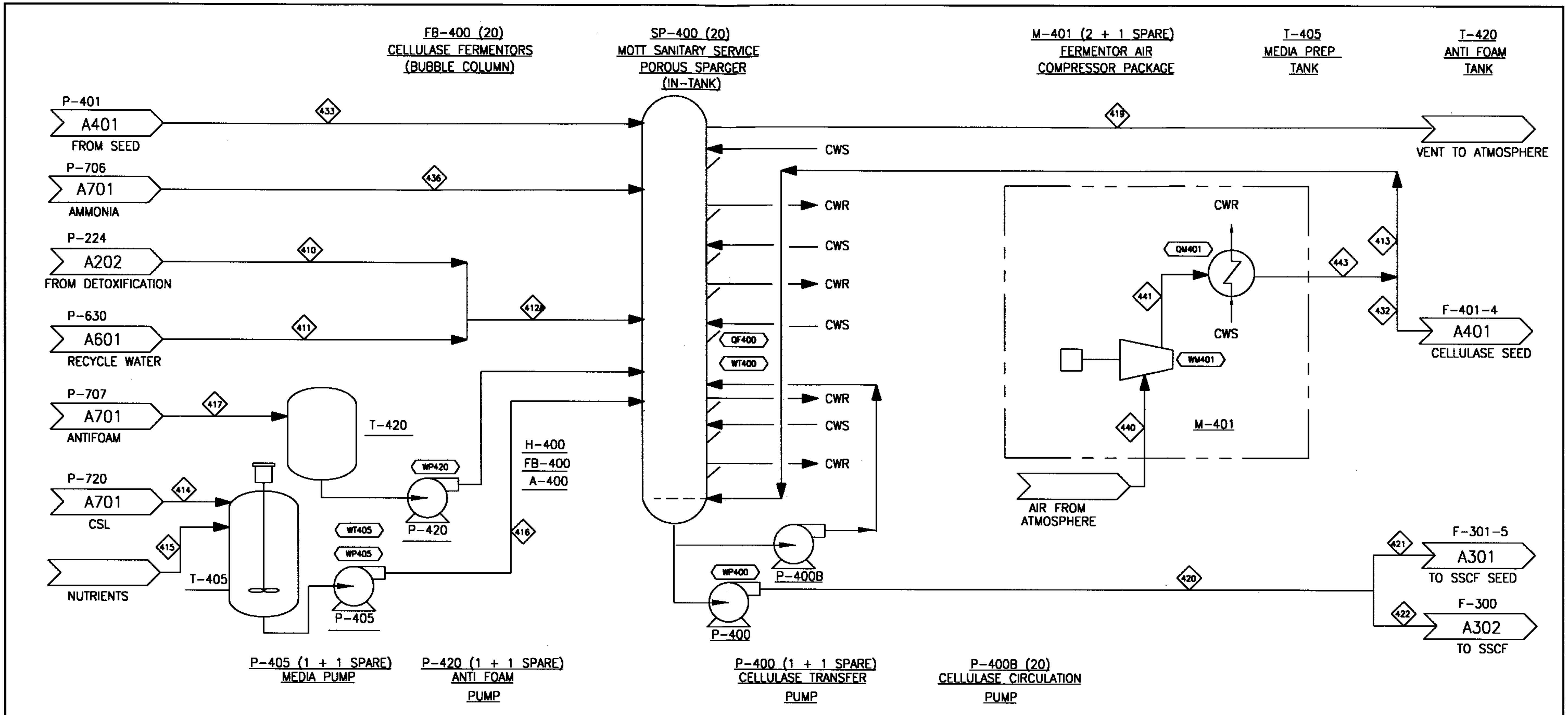
NREL

PROCESS FLOW DIAGRAM
SECTION A400
CELLULASE PROD. FEMENTATION

PROJECT NUMBER	DRAWING NUMBER	
9827	D-400-N-A402	A
Client	Size / Area / Type / Sequence	Rev.

D400NA402.DWG

02/11/00



STREAM NUMBER	UNITS	410	411	412A	413	414	415	416	417	419	420	421	422	432	433	436	440	441	443
STREAM NAME																			
TOTAL FLOW	kg/hr	18,176.0	22,784.0	40,960.0	301,966.0	406.0	174.0	580.0	227.0	307,253.0	39,217.0	3,922.0	35,296.0	20,928.0	2,580.0	157.0	322,894.0	322,894.0	322,894.0
INSOLUBLE SOLIDS	%	16.2%	0.2%	7.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.6%	5.6%	5.6%	0.0%	4.7%	0.0%	0.0%	0.0%	0.0%
SOLUBLE SOLIDS	%	6.3%	1.1%	3.4%	0.0%	100.0%	0.0%	69.9%	0.0%	0.0%	1.7%	1.7%	1.7%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%
TEMPERATURE	°C	59	47	48	40	28	28	28	28	28	28	28	28	40	28	28	20	169	40
PRESSURE	atm	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.66	1.66	1.66	1.66	1.00	1.00	1.00	1.00	3.00	1.00
ETHANOL	kg/hr	3.0	3.0	6.0	0.0	0.0	0.0	0.0	0.0	4.0	2	0.0	2.00	0.0	0.0	0.0	0.0	0.0	0.0
WATER	kg/hr	13,880.0	22,117.0	35,996.0	0.0	0.0	0.0	0.0	0.0	4,263.0	35,489.0	3,549.0	31,940.0	0.0	2,382.0	0.0	0.0	0.0	0.0
GLUCOSE (SS)	kg/hr	128.0	0.0	128.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XYLOSE (SS)	kg/hr	682.0	19.0	701.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACETIC ACID	kg/hr	79.0	78.0	157.0	0.0	0.0	0.0	0.0	0.0	12.0	155.0	15.0	139.0	0.0	10.0	0.0	0.0	0.0	0.0
CELLULOSE (IS)	kg/hr	1,634.0	3.0	1,636.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHERS	kg/hr	1,770.0	564.0	2,336.0	301,966.0	406.0	174.0	580.0	227.0	302,974.0	3,571.0	358.0	3,215.0	20,928.0	198.0	157.0	322,894.0	322,894.0	322,894.0

DWG. No.	REFERENCE DRAWINGS	No.	DATE	REVISION	BY	CK'D	APPR.
		A	02/15/00	PRELIMINARY	PRR	PT	

ENGINEERING RECORD
DATE: 01/25/00
SCALE: NONE
DRAWN BY: LANIER
CHECKED BY: PT
APPROVAL:
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VB
VOGELBUSCH USA, INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS

NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Biotechnology Center For Fuels And Chemicals

NREL

PROCESS FLOW DIAGRAM
SECTION A400
CELLULASE PROD. FEMENTATION

PROJECT NUMBER	DRAWING NUMBER	
9827	D-400-N-A402B	A
Client	Size Area Type Sequence	Rev.

D400N4402B.DWG

02/15/00

EQUIPMENT LIST (BUBBLE COLUMN ALTERNATIVE)

VOGELBUSCH U.S.A., INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS 77043-5013
(713) 461-7374 / (713) 461-7377 FAX

CLIENT: **NREL**
GOLDEN, CO
PROJ: **9827**
AREA: 400 - CELLULASE PRODUCTION
PFD: D-400-N-A401 / A402B

MADE BY: PT
APPD BY:
PRINT: 5/11/00
PAGE: 1 OF 2

REVISIONS

NO.	DATE	BY
A	2/1/00	PT

EQUIPMENT GROUP: EXCHANGERS

EQUIP NUMBER	EQUIPMENT DESCRIPTION NAME	NO.	CAPACITY MM BTU/HR	SIZE TYPE	SIZE SQFT	SIZE U VAL	DESIGN PRESS SHELL	DESIGN PRESS TUBE	D.TEMP ºF	MATERIALS SHELL	MATERIALS TUBE	COST ESTIMATE $ / ITEM	COST ESTIMATE TOTAL $	REMARKS
		0		WPLAT	0		150	125	200	304L SS	304L SS	$0	$0	
SUBTOTAL	EXCHANGERS	0											$0	

EQUIPMENT GROUP: PUMPS

EQUIP NUMBER	EQUIPMENT DESCRIPTION NAME	NO.	CAPACITY GALS/MIN	SIZE (IN) SUCT	SIZE (IN) DISCH	SIZE (IN) IMP	PRESS FEET	D.TEMP ºF	MATL	MOTOR HP	MOTOR RPM	COST ESTIMATE $ / ITEM	COST ESTIMATE TOTAL $	REMARKS
P-400	CELLULASE TRANSFER PUMP	2	175				100	212	316 SS			$10,004	$20,008	DELTA T COST = $9,300/ITEM
P-400A	CELLULASE CIRC. PUMP	20	100				125	212	316 SS			$8,235	**$164,691**	**NEW RECIRCULATION PUMPS**
P-401	CELLULASE SEED PUMP	2	72.5				N.A.	212	316 SS			$12,105	$24,210	ROTARY LOBE - DELTA T COST USED
P-405	MEDIA PUMP	2	62.5				100	212	316 SS	22		$7,350	$14,700	DELTA T COST = $8,300 / ITEM
P-420	ANTI-FOAM PUMP	2	11.2				75	212	316 SS	129		$6,140	$12,280	DELTA T COST = $5,500 / ITEM
SUBTOTAL	PUMPS	28								302			$235,888	

EQUIPMENT LIST (BUBBLE COLUMN ALTERNATIVE)

VOGELBUSCH U.S.A., INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS 77043-5013
(713) 461-7374 / (713) 461-7377 FAX

CLIENT: **NREL**
GOLDEN, CO
PROJ: **9827**
AREA: 400 - CELLULASE PRODUCTION
PFD: D-400-N-A401/A402 B

MADE BY: PT
APPD BY:
PRINT: 5/11/00
PAGE: 2 OF 2

REVISIONS

NO.	DATE	BY
A	2/1/00	PT

EQUIPMENT GROUP: AGITATORS

EQUIP NUMBER	EQUIPMENT DESCRIPTION NAME	NO:	TANK CAP GALLONS	S I Z E (FT) DIA	S.SIDE	SHAFT DIA IN	MOUNT TYPE	D.TEMP ºF	MATL	AGITATOR HP	RPM	COST ESTIMATE $ / ITEM	TOTAL $	REMARKS
		0	281,708	36	37		TOP	250	304 SS				$0	
SUBTOTAL	AGITATORS	0								0			$0	

EQUIPMENT GROUP: TANKS/VESSELS

EQUIP NUMBER	EQUIPMENT DESCRIPTION NAME	NO:	CAPACITY GALLONS	S I Z E (FT) DIA	S.SIDE		PRESS PSIG	D.TEMP ºF	MATL	DESIGN CODE DESIGN	NO.	COST ESTIMATE $ / ITEM	TOTAL $	REMARKS
FB-400	BUBBLE COLUMN FERMENT.	20	147,387	16	98		25.0		GLASS			$225,000	$4,500,000	VOGELBUSCH ESTIMATE
F-401	JACKETED SEED VESSEL	3	36	1.75	2		15.0		304 SS			$22,500	$67,500	W/AGITATOR -DELTA T COST USED
F-402	JACKETED SEED VESSEL	3	663	4.8	4.9		15.0		304 SS			$54,100	$162,300	W/AGITATOR -DELTA T COST USED
F-403	JACKETED SEED VESSEL	3	13,215	13	13.31		15.0		304 SS			$282,100	$846,300	W/AGITATOR -DELTA T COST USED
T-405	MEDIA PREP TANK	1	6,270	9.85	11				304 SS			$64,600	$64,600	W/AGITATOR -DELTA T COST USED
T-420	ANTIFOAM TANK	1	211	3	4				PLYETH			$402	$402	POLYETHYLENE - DELTA T COST USED
SUBTOTAL	TANKS/VESSELS	31											$5,641,102	

EQUIPMENT GROUP: MISCELLANEOUS

EQUIP NUMBER	EQUIPMENT DESCRIPTION NAME	NO:	CAPACITY AIR	UNITS		UNITS	DESIGN PSIG	ºF	MATL	MOTOR HP	RPM	COST ESTIMATE $ / ITEM	TOTAL $	REMARKS
M-101	AIR COMPRESSOR PACKAGE	3	22,271	SCFM			75			4000		$596,342	$1,789,026	DELTA T COST USED
SP-400	IN-LINE AIR SPARGER	20	60,000	#/HR					316LSS			$3,833	**$76,660**	**MOTT METALURGICAL QUOTE - 01/00**
SP-401	IN-TANK AIR SPARGER	9	4,332	#/HR					316LSS			$125	**$1,125**	**MOTT METALURGICAL QUOTE - 01/00**
SUBTOTAL	OTHER EQUIPMENT	32								0			$1,866,811	

AREA 400 EQUIP COST ESTIMATE
$7,743,801

AREA 400 OVERALL SAVINGS (COST) VS. NREL ORIGINAL CASE
$3,642,700

AREA 400 DELTA INCREASE (DECREASE)	
FERMENTERS	**$2,520,528**
PUMPS	**$164,691**
SPARGERS	**$77,785**
AGITATORS	**($6,050,000)**
FERM. COILS	**($355,704)**

EQUIPMENT LIST (SPARGER ALTERNATIVE)

VOGELBUSCH U.S.A., INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS 77043-5013
(713) 461-7374 / (713) 461-7377 FAX

CLIENT: **NREL**
GOLDEN, CO
PROJ: **9827**
AREA: 400 - CELLULASE PRODUCTION
PFD: D-400-N-A401/A402

MADE BY: PT
APPD BY:
PRINT: 5/11/00
PAGE: 2 OF 2

REVISIONS

NO.	DATE	BY
A	2/1/00	PT

EQUIPMENT GROUP: AGITATORS

EQUIP NUMBER	EQUIPMENT DESCRIPTION NAME	NO:	TANK CAP GALLONS	S I Z E (FT) DIA	S.SIDE	SHAFT DIA IN	MOUNT TYPE	D.TEMP ºF	MATL	AGITATOR HP	RPM	COST ESTIMATE $ / ITEM	TOTAL $	REMARKS
A-400	CELLULASE FERM. AGIT.	11	281,708	36	37		TOP	250	304 SS	600		$550,000	$6,050,000	VERY LARGE HP - DELTA T COST USED
SUBTOTAL	AGITATORS	11								6600			$6,050,000	

EQUIPMENT GROUP: TANKS/VESSELS

EQUIP NUMBER	EQUIPMENT DESCRIPTION NAME	NO:	CAPACITY GALLONS	S I Z E (FT) DIA	S.SIDE		PRESS PSIG	D.TEMP ºF	MATL	DESIGN CODE DESIGN	NO.	COST ESTIMATE $ / ITEM	TOTAL $	REMARKS
F-400	CELLULASE FERMENTERS	11	281,708	36	37		25.0		304 SS			$179,952	$1,979,472	PRESSURE VESSEL - DELTA T COST USED
F-401	JACKETED SEED VESSEL	3	36	1.75	2		15.0		304 SS			$22,500	$67,500	W/AGITATOR -DELTA T COST USED
F-402	JACKETED SEED VESSEL	3	663	4.8	4.9		15.0		304 SS			$54,100	$162,300	W/AGITATOR -DELTA T COST USED
F-403	JACKETED SEED VESSEL	3	13,215	13	13.31		15.0		304 SS			$282,100	$846,300	W/AGITATOR -DELTA T COST USED
T-405	MEDIA PREP TANK	1	6,270	9.85	11				304 SS			$64,600	$64,600	W/AGITATOR -DELTA T COST USED
T-420	ANTIFOAM TANK	1	211	3	4				PLYETH			$402	$402	POLYETHYLENE - DELTA T COST USED
SUBTOTAL	TANKS/VESSELS	22											$3,120,574	

EQUIPMENT GROUP: MISCELLANEOUS

EQUIP NUMBER	EQUIPMENT DESCRIPTION NAME	NO:	CAPACITY AIR	UNITS		UNITS	DESIGN PSIG	ºF	MATL	MOTOR HP	RPM	COST ESTIMATE $ / ITEM	TOTAL $	REMARKS
M-101	AIR COMPRESSOR PACKAGE	3	22,271	SCFM			55			4000		$596,342	$1,789,026	DELTA T COST USED
SP-400	IN-LINE AIR SPARGER	11	60,000	#/HR					316LSS			$3,833	**$42,163**	**MOTT METALURGICAL QUOTE - 01/00**
SP-401	IN-TANK AIR SPARGER	9	4,332	#/HR					316LSS			$125	**$1,125**	**MOTT METALURGICAL QUOTE - 01/00**
SUBTOTAL	OTHER EQUIPMENT	23								0			$1,832,314	

AREA 400
EQUIP COST ESTIMATE
$11,520,370

AREA 400
MODIFICATION COST
$133,868

EQUIPMENT LIST (SPARGER ALTERNATIVE)

VOGELBUSCH U.S.A., INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS 77043-5013
(713) 461-7374 / (713) 461-7377 FAX

CLIENT: **NREL**
GOLDEN, CO
PROJ: **9827**
AREA: 400 - CELLULASE PRODUCTION
PFD: D-400-N-A401/A402

MADE BY: PT
APPD BY:
PRINT: 5/11/00
PAGE: 1 OF 2

REVISIONS

NO.	DATE	BY
A	2/1/00	PT

EQUIPMENT GROUP: EXCHANGERS

EQUIP	EQUIPMENT DESCRIPTION	NO.	CAPACITY	SIZE			DESIGN PRESS		D.TEMP	MATERIALS		COST ESTIMATE		REMARKS
NUMBER	NAME		MM BTU/HR	TYPE	SQFT	U VAL	SHELL	TUBE	ºF	SHELL	TUBE	$ / ITEM	TOTAL $	
H-400	CELLULASE FERM. COILS	11		WPLAT	613		150	125	200	304L SS	304L SS	$32,337	$355,704	DELTA T COST = $34,400/ITEM
SUBTOTAL	EXCHANGERS	11											$355,704	

EQUIPMENT GROUP: PUMPS

EQUIP	EQUIPMENT DESCRIPTION	NO.	CAPACITY	S I Z E (IN)			PRESS	D.TEMP	MATL	MOTOR		COST ESTIMATE		REMARKS
NUMBER	NAME		GALS/MIN	SUCT	DISCH	IMP	FEET	ºF		HP	RPM	$ / ITEM	TOTAL $	
P-400	CELLULASE TRANSFER PUMP	2	175				100	212	316 SS			$10,004	$20,008	DELTA T COST = $9,300/ITEM
P-400A	CELLULASE CIRC. PUMP	11	100				85	212	316 SS			$8,235	**$90,580**	**NEW RECIRCULATION PUMPS**
P-401	CELLULASE SEED PUMP	2	72.5				N.A.	212	316 SS			$12,105	$24,210	ROTARY LOBE - DELTA T COST USED
P-405	MEDIA PUMP	2	62.5				100	212	316 SS	22		$7,350	$14,700	DELTA T COST = $8,300 / ITEM
P-420	ANTI-FOAM PUMP	2	11.2				75	212	316 SS	129		$6,140	$12,280	DELTA T COST = $5,500 / ITEM
SUBTOTAL	PUMPS	19								302			$161,777	

VOGELBUSCH U.S.A., INC.
10810 OLD KATY RD, SUITE 107
HOUSTON, TEXAS 77043
PHONE: (713) 461-7374
FAX: (713) 461-7377

DATA SHEET
STERILE AIR SPARGER - IN-LINE
TYPE: NON-INTRUSIVE

		SHEET NO.: **SP-400**		**FERMENTER AIR SPARGER**	
CLIENT:	**NREL**	REV.	DESCRIPTION	BY	DATE
LOCATION:	**GOLDEN, COLORADO**	**A**	**PRELIMINARY**	**PT**	**20-Jan-00**
UNIT:	**400 - CELLULASE FERMENT.**				
JOB NO.:	**9922**				
ITEM NO.:	**SP-400**				

APPLICABLE TO :
- [X] INQUIRY
- [ ] PURCHASE
- [ ] AS-BUILT

P.O. NO.: MODEL NO.:
SERVICE: **STERILE AIR SPARGING** TYPE: **NON-INTRUSIVE**
MANUFACTURER:
OF UNITS: **1** DWG ATTACHED:

PERFORMANCE OF ONE UNIT

	UNITS	MINIMUM	NORMAL	MAXIMUM
GAS THROUGH DIFFUSER	---	**STERILE COMPRESSED AIR (FILTERED TO 0.2 MICRON)**		
GAS FLOWRATE	ACFM		**3,822**	**4,586**
GAS FLOWRATE	#/HR		**60,531**	**72,637**
AIR PRESSURE	PSIG		**44 (NOTE 7)**	
AIR TEMPERATURE	ºF		**104**	
LIQUID THROUGH DIFFUSER	---		**BROTH**	
LIQUID FLOW RATE	GPM		**100**	
LIQUID FLOW RATE	#/HR		**50,040**	
TEMPERATURE	°F		**82**	
PRESSURE	PSIG		**(NOTE 7)**	
SPECIFIC GRAVITY	---		**1.02**	
VISCOSITY	cP		**100**	
PRESSURE DROP	PSI		*	
DIAMETER	INCHES		*	
LENGTH	INCHES		*	
PIPE DIAMETER	INCHES			

CONSTRUCTION OF ONE UNIT

MATERIAL OF CONSTRUCTION: **316 SS**

REMARKS

1. **USED FOR SPARGING AIR TO A FERMENTER TO SUPPORT MICROBIAL GROWTH.**
2. **PLEASE QUOTE A MOTT GASSAVER SANITARY SPARGER.**
3. **PROVIDE DIMENSIONS AND PRESSURE DROP (GAS AND LIQUID SIDES).**
4. **PROVIDE MICRON SIZE OF UNIT.**
5. **UNIT WILL BE PERIODICALLY EXPOSED TO 150 PSI STEAM FOR STERILIZATION.**
6. **UNIT WILL BE EXPOSED TO A 5% CAUSTIC SOLUTION (180ºF) FOR SHORT PERIODS OF TIME (1 - 2 HOURS).**
7. **AIR PRESSURE STATED CORRESPONDS TO ACFM FLOW. IT WILL BE ADJUSTED, IF NECESSARY, BASED ON FINAL PUMP PROPERTIES. PLEASE SIZE UNIT FOR STATED AIR CONDITIONS.**

PRINT DATE: 5/11/00

* INFORMATION TO BE SUPPLIED BY VENDOR

VOGELBUSCH U.S.A., INC.
10810 OLD KATY RD, SUITE 107
HOUSTON, TEXAS 77043
PHONE: (713) 461-7374
FAX: (713) 461-7377

DATA SHEET
STERILE AIR SPARGER - IN-LINE
TYPE: NON-INTRUSIVE

SHEET NO.:	SP-400 (PILOT)	FERMENTER AIR SPARGER	
REV.	DESCRIPTION	BY	DATE
A	PRELIMINARY	PT	20-Jan-00

CLIENT:	NREL
LOCATION:	GOLDEN, COLORADO
UNIT:	400 - CELLULASE FERMENT.
JOB NO.:	9922
ITEM NO.:	SP-400 (PILOT)

APPLICABLE TO :
- [X] INQUIRY
- [ ] PURCHASE
- [ ] AS-BUILT

P.O. NO.:		MODEL NO.:	
SERVICE:	STERILE AIR SPARGING	TYPE:	NON-INTRUSIVE
MANUFACTURER:			
# OF UNITS:	1	DWG ATTACHED:	

PERFORMANCE OF ONE UNIT

	UNITS	MINIMUM	NORMAL	MAXIMUM
GAS THROUGH DIFFUSER	---	STERILE COMPRESSED AIR (FILTERED TO 0.2 MICRON)		
GAS FLOWRATE	ACFM		13	16
GAS FLOWRATE	#/HR		203	244
AIR PRESSURE	PSIG		44 (NOTE 7)	
AIR TEMPERATURE	ºF		104	
LIQUID THROUGH DIFFUSER	---		BROTH	
LIQUID FLOW RATE	GPM		20	
LIQUID FLOW RATE	#/HR		10,008	
TEMPERATURE	°F		82	
PRESSURE	PSIG		(NOTE 7)	
SPECIFIC GRAVITY	---		1.02	
VISCOSITY	cP		100	
PRESSURE DROP	PSI		*	
DIAMETER	INCHES		*	
LENGTH	INCHES		*	
PIPE DIAMETER	INCHES			

CONSTRUCTION OF ONE UNIT

MATERIAL OF CONSTRUCTION: **316 SS**

REMARKS

1. USED FOR SPARGING AIR TO A FERMENTER TO SUPPORT MICROBIAL GROWTH.
2. PLEASE QUOTE A MOTT GASSAVER SANITARY SPARGER.
3. PROVIDE DIMENSIONS AND PRESSURE DROP (GAS AND LIQUID SIDES).
4. PROVIDE MICRON SIZE OF UNIT.
5. UNIT WILL BE PERIODICALLY EXPOSED TO 150 PSI STEAM FOR STERILIZATION.
6. UNIT WILL BE EXPOSED TO A 5% CAUSTIC SOLUTION (180ºF) FOR SHORT PERIODS OF TIME (1 - 2 HOURS).
7. AIR PRESSURE STATED CORRESPONDS TO ACFM FLOW. IT WILL BE ADJUSTED, IF NECESSARY, BASED ON FINAL PUMP PROPERTIES. PLEASE SIZE UNIT FOR STATED AIR CONDITIONS.

PRINT DATE: 5/11/00

* INFORMATION TO BE SUPPLIED BY VENDOR

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10810 OLD KATY RD, SUITE 107
HOUSTON, TEXAS 77043
PHONE: (713) 461-7374
FAX: (713) 461-7377

DATA SHEET
STERILE AIR SPARGER - IN-LINE
TYPE: NON-INTRUSIVE

		SHEET NO.: **SP-401**		**FERMENTER AIR SPARGER**	
CLIENT:	**NREL**	REV.	DESCRIPTION	BY	DATE
LOCATION:	**GOLDEN, COLORADO**	**A**	**PRELIMINARY**	**PT**	**20-Jan-00**
UNIT:	**400 - CELLULASE FERMENT.**				
JOB NO.:	**9922**				
ITEM NO.:	**SP-401**				

APPLICABLE TO :	P.O. NO.:		MODEL NO.:
X INQUIRY	SERVICE:	**STERILE AIR SPARGING**	TYPE: **IN-TANK**
PURCHASE	MANUFACTURER:		
AS-BUILT	# OF UNITS:	**1**	DWG ATTACHED:

PERFORMANCE OF ONE UNIT

	UNITS	MINIMUM	NORMAL	MAXIMUM
GAS THROUGH DIFFUSER	---	**STERILE COMPRESSED AIR (FILTERED TO 0.2 MICRON)**		
GAS FLOWRATE	ACFM		**275**	**330**
GAS FLOWRATE	#/HR		**4,332**	**5,198**
AIR PRESSURE	PSIG		**44**	
AIR TEMPERATURE	ºF		**104**	
LIQUID IN TANK	---		**BROTH**	
TANK VOLUME	GALLONS		**13,200**	
TANK HEIGHT	FT		**14**	
TEMPERATURE	°F		**82**	
LIQUID PRESSURE	PSIG		**6**	
HEAD PRESSURE	PSIG		**15**	
TOTAL PRESSURE	PSIG		**21**	
SPECIFIC GRAVITY	---		**1.02**	
VISCOSITY	cP		**100**	
PRESSURE DROP	PSI		*	
DIAMETER	INCHES		*	
LENGTH	INCHES		*	
PIPE DIAMETER	INCHES			

CONSTRUCTION OF ONE UNIT

MATERIAL OF CONSTRUCTION: **316 SS**

REMARKS

1. **USED FOR SPARGING AIR TO A FERMENTER TO SUPPORT MICROBIAL GROWTH.**
2. **PLEASE QUOTE A MOTT IN-TANK SPARGER CONFIGURATION.**
3. **PROVIDE DIMENSIONS AND PRESSURE DROP (GAS AND LIQUID SIDES).**
4. **PROVIDE MICRON SIZE OF UNIT.**
5. **UNIT WILL BE PERIODICALLY EXPOSED TO 150 PSI STEAM FOR STERILIZATION.**
6. **UNIT WILL BE EXPOSED TO A 5% CAUSTIC SOLUTION (180ºF) FOR SHORT PERIODS OF TIME (1 - 2 HOURS).**
7. **UNIT WILL BE IN SANITARY SERVICE IN A PRESSURIZED VESSEL.**

PRINT DATE: 5/11/00

* INFORMATION TO BE SUPPLIED BY VENDOR

VOGELBUSCH U.S.A., INC.
10810 OLD KATY RD, SUITE 107
HOUSTON, TEXAS 77043
PHONE: (713) 461-7374
FAX: (713) 461-7377

DATA SHEET
STERILE AIR SPARGER - IN-LINE
TYPE: NON-INTRUSIVE

		SHEET NO.: **SP-401 (PILOT)**	**FERMENTER AIR SPARGER**		
CLIENT:	**NREL**	REV.	DESCRIPTION	BY	DATE
LOCATION:	**GOLDEN, COLORADO**	**A**	**PRELIMINARY**	**PT**	**20-Jan-00**
UNIT:	**400 - CELLULASE FERMENT.**				
JOB NO.:	**9922**				
ITEM NO.:	**SP-401 (PILOT)**				

APPLICABLE TO :
- [X] INQUIRY
- [ ] PURCHASE
- [ ] AS-BUILT

P.O. NO.: MODEL NO.:
SERVICE: **STERILE AIR SPARGING** TYPE: **IN-TANK**
MANUFACTURER:
OF UNITS: **1** DWG ATTACHED:

PERFORMANCE OF ONE UNIT

	UNITS	MINIMUM	NORMAL	MAXIMUM
GAS THROUGH DIFFUSER	---	**STERILE COMPRESSED AIR (FILTERED TO 0.2 MICRON)**		
GAS FLOWRATE	ACFM		**13**	**16**
GAS FLOWRATE	#/HR		**203**	**244**
AIR PRESSURE	PSIG		**44**	
AIR TEMPERATURE	ºF		**104**	
LIQUID IN TANK	---		**BROTH**	
TANK VOLUME	GALLONS		**400**	
TANK HEIGHT	FT		**5**	
TEMPERATURE	°F		**82**	
LIQUID PRESSURE	PSIG		**2**	
HEAD PRESSURE	PSIG		**15**	
TOTAL PRESSURE	PSIG		**17**	
SPECIFIC GRAVITY	---		**1.02**	
VISCOSITY	cP		**100**	
PRESSURE DROP	PSI		*	
DIAMETER	INCHES		*	
LENGTH	INCHES		*	
PIPE DIAMETER	INCHES			

CONSTRUCTION OF ONE UNIT

MATERIAL OF CONSTRUCTION: **316 SS**

REMARKS

1. **USED FOR SPARGING AIR TO A FERMENTER TO SUPPORT MICROBIAL GROWTH.**
2. **PLEASE QUOTE A MOTT IN-TANK SPARGER CONFIGURATION.**
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7. **UNIT WILL BE IN SANITARY SERVICE IN A PRESSURIZED VESSEL.**

PRINT DATE: 5/11/00

* INFORMATION TO BE SUPPLIED BY VENDOR

mott *corporation*

84 Spring Lane, Farmington, CT 06032-3159
860-747-6333 Fax 860-747-6739

ISO 9001 CERTIFIED

QUOTATION# 15790AF
CUSTOMER # 42651

FAX TRANSMITTAL Phone: 860-747-6333 Fax: 860-747-6739

NUMBER 713-461-7377 DATE February 1, 2000

TO Pam Tetarenko FROM Bruce Kobles

COMPANY VOGELBUSCH PHONE 713-461-7374

ADDRESS
10810 Old Katy Road, Suite 107, Houston TX 77043

REFERENCE Your Fax dated January 20, 2000

CONFIRMATION WILL BE SENT VIA MAIL ☒ No PAGES (INCLUDING COVER SHEET) 2

We are pleased to provide you with the following quotation:

DESCRIPTION	QUANTITY	PRICE (Each)
Mott S71 Series Sanitary GasSaver 100 gpm unit Mott P/N S71E24B65-E34F2AB-65 316LSS porous/316SS hardware **Estimated Lead Time: 6 to 8 weeks after receipt of order.**	1	$3,833.00
Mott S71 Series Sanitary GasSaver 30 gpm unit Mott P/N S71D24B65-D18F2AB-65 316LSS porous/316SS hardware **Estimated Lead Time: 6 to 8 weeks after receipt of order.**	1	$3,124.00
Mott 2200 Series Rolled and Welded Sintered Porous Metal Sparger Mott Catalog # 2232-A08-10-A00-2-AB 2.00" OD x 10.00" long porous with a ½" Hex nipple connection on one end and the other end blind, 2 µm grade 316LSS porous/316SS hardware **Estimated Lead Time: 6 to 8 weeks after receipt of order.**	70	$125.00
Mott 2200 Series Rolled and Welded Sintered Porous Metal Sparger Mott Catalog # 2224-A04-10-A00-2-AB 1.50" OD x 10.00" long porous with a ¼" Hex nipple connection on one end and the other end blind, 2 µm grade 316LSS porous/316SS hardware **Estimated Lead Time: 4 to 5 weeks after receipt of order.**	5	$134.00

Items in stock are subject to prior sale.

Certificates of compliance and material certification are available on request at time of original order placement, whether verbal or written, for a fee of $25.00 each per order. It may not be possible to provide certifications after the initial order is processed, and when possible a charge of $100.00 each will apply.

Please reference the above noted quotation number on all orders or correspondence pertaining to this quote.

MasterCard & Visa now accepted.
Minimum purchase is $500.00. Quotation Valid If Purchase Order Received Within 60 Days.
Terms: Net 30 Days-Subject to Credit Approval FOB Farmington, CT

mott *corporation*

Quote 15790AF
Vogelbusch
Attn: Pam Tetarenko
Page 2

If you have any questions or require further information, please do not hesitate to contact us or our representative in your area:

TECH FILTER AND EQUIPMENT, INC.
16637-F West Hardy Road, Houston TX 77060
E-mail: filter@techfilter.com
Web site: www.techfilter.com
Phone: 888-300-8191 Fax: 281-873-0220

Thank you for your inquiry. We look forward to receiving your order.

Best regards,

Bruce Kobles
Technical Service Representative
BK/bv

cc: 028

VOGELBUSCH U.S.A.,INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS 77043
TELEPHONE: 713/461-7374
TELEFAX: 713/461-7377

PUMP CALCULATION SHEET

CLIENT : NREL PROJ.No: 9827

PUMP NO : P-400 A AREA : 400 Cellulase
SERVICE : CELLULASE CIRCULATION PUMP

REV	DESCRIPTION	BY	DATE
A	PRELIMINARY	PT	02/01/00

SCHEMATIC OF PUMP LAYOUT
TRANSFER/ CIRCULATION PUMP

<--LOOP "A" (SP-400)

ORIGIN VESSEL	
AREA :	400
EQU.NO :	F-400
SSIDE :	37
TOP ELEV:	37
SPGR HD:	37
DESIGN CONDITIONS	
OP.PRESSURE	
PSIG :	25
FVOL % :	30%
FVOL FT :	11.1

SUCT.LINE
SIZE (IN):

SPGR:	SP-400
DP NORM:	10
DP MAX:	12

AIR (NOTE 1)

PUMP No:	P-1400
EFF %:	65%

DISCH.LINE
SIZE (IN):

Indicate pressure and elevations for each equipment item

		TOTAL SUCTION	LOOP	LOOP A	LOOP
SUCTION PRESSURE					
@ ORIGIN	psig	25.0			
STATIC HEAD (ft x sp.gr. /2.31)	psi	4.9			
- LOSS (LINE OR OTHER)	psi	-1.0			
PUMP SUCTION PRESSURE	psig	28.9			
NET POSITIVE SUCTION HEAD					
STATIC HEAD	feet	11.1			
- LINE LOSS (psi x 2.31/ sp.gr.)	feet	-2.3			
+(Origin Press-V.P.)(2.31/sp.gr.)	feet	86.7			
SAFETY FACTOR	feet	-1.0			
AVAILABLE NPSH	feet	94.6			
DISCHARGE PRESSURE					
DELIVERY PRESSURE	psig			25.0	
DELIVERY HEAD(FeetxSG/ 2.31)	psi			16.3	
LINE LOSS (Feet x SG / 2.31)	psi			10.0	
CONTROL VALVE DP	psi				
GASSAVER (SP-400)	psi			12.0	
OTHER *	psi			2.0	
PUMP DISCHARGE PRESSURE	psig		0.0	65.3	0.0
DIFFERENTIAL PRESSURE					
DISCHARGE PRESSURE	psig	65.3		65.3	
SUCTION PRESSURE	psig	28.9		28.9	
TOTAL PUMP DIFF.PRESSURE	psi	36.4		36.4	
TOTAL PUMP DIFF.PRESSURE psi x 2.31 / sp.gr.	Feet	82.5			
ESTIMATED BRAKE HORSEPOWER					
GPM x DIFF PSI = BHP 1715 x 0.6 (Default Pump Eff.)		3.3			

* MINIMUM 2 PSI FOR DYNAMIC HEAD

PHYSICAL DATA		TOTAL SUCTION	LOOP	LOOP A	LOOP
LIQUID PUMPED :		BROTH			
TEMPERATURE F :	°F	82.0		82.0	
VISCOSITY cp	cp	1000.0		1000.0	
VAP.PRESS.NORMA	psia	0.6			
VAP.PRESS.MAX :	psia	0.7			
SPEC.GRAVITY :	SG	1.02			
DENSITY :	#/cuft	63.43			
NORMAL FLOW :	gpm	100.0		100.0	
PEAK FLOW :	gpm	100.0		100.0	
ATM.PRESSURE	psia	14.0 ACTUAL	14.0 **ACTUAL**		

NOTES:

1) AIR SUPPLY PRESSURE NEEDS TO BE GREATER THAN THE LIQUID PRESSURE + 10 PSI DELTA P ACROSS GAS SIDE OF GASSAVER.

VOGELBUSCH U.S.A.,INC.
10810 OLD KATY ROAD, SUITE 107
HOUSTON, TEXAS 77043
TELEPHONE: 713/461-7374
TELEFAX: 713/461-7377

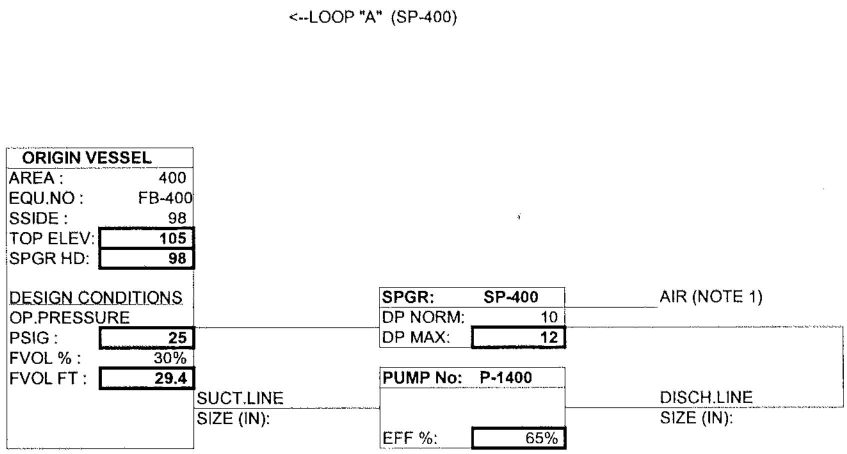
PUMP CALCULATION SHEET

CLIENT : NREL PROJ.No: 9827

PUMP NO : P-400 B AREA : 400 Bubble Col.
SERVICE : CELLULASE CIRCULATION PUMP

REV	DESCRIPTION	BY	DATE
A	PRELIMINARY	PT	02/01/00

SCHEMATIC OF PUMP LAYOUT
TRANSFER/ CIRCULATION PUMP



Indicate pressure and elevations for each equipment item

		TOTAL SUCTION	LOOP	LOOP A	LOOP
SUCTION PRESSURE					
@ ORIGIN	psig	25.0			
STATIC HEAD (ft x sp.gr. /2.31)	psi	13.0			
- LOSS (LINE OR OTHER)	psi	-1.0			
PUMP SUCTION PRESSURE	psig	37.0			
NET POSITIVE SUCTION HEAD					
STATIC HEAD	feet	29.4			
- LINE LOSS (psi x 2.31/ sp.gr.)	feet	-2.3			
+(Origin Press-V.P.)(2.31/sp.gr.)	feet	86.7			
SAFETY FACTOR	feet	-1.0			
AVAILABLE NPSH	feet	112.9			
DISCHARGE PRESSURE					
DELIVERY PRESSURE	psig			25.0	
DELIVERY HEAD(FeetxSG/ 2.31)	psi			43.3	
LINE LOSS (Feet x SG / 2.31)	psi			10.0	
CONTROL VALVE DP	psi				
GASSAVER (SP-400)	psi			12.0	
OTHER *	psi			2.0	
PUMP DISCHARGE PRESSURE	psig		0.0	92.3	0.0
DIFFERENTIAL PRESSURE					
DISCHARGE PRESSURE	psig	92.3		92.3	
SUCTION PRESSURE	psig	37.0		37.0	
TOTAL PUMP DIFF.PRESSURE	psi	55.3		55.3	
TOTAL PUMP DIFF.PRESSURE psi x 2.31 / sp.gr.	Feet	125.2			
ESTIMATED BRAKE HORSEPOWER GPM x DIFF PSI / 1715 x 0.6 (Default Pump Eff.)	= BHP	5.0			

* MINIMUM 2 PSI FOR DYNAMIC HEAD

PHYSICAL DATA		TOTAL SUCTION	LOOP	LOOP A	LOOP
LIQUID PUMPED :		BROTH			
TEMPERATURE F :	°F	82.0		82.0	
VISCOSITY cp	cp	1000.0		1000.0	
VAP.PRESS.NORMAL	psia	0.6			
VAP.PRESS.MAX :	psia	0.7			
SPEC.GRAVITY :	SG	1.02			
DENSITY :	#/cuft	63.43			
NORMAL FLOW :	gpm	100.0		100.0	
PEAK FLOW :	gpm	100.0		100.0	
ATM.PRESSURE	psia	14.0 ACTUAL	14.0 **ACTUAL**		

NOTES:

1) AIR SUPPLY PRESSURE NEEDS TO BE GREATER THAN THE LIQUID PRESSURE + 10 PSI DELTA P ACROSS GAS SIDE OF GASSAVER.